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Documentation of the LLNL, TAFB and TSLMicro-Computed-Tomography Systems

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Disclaimer

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Executive Summary:

This document details the microCT data collection systems in use at the Transportation Security Laboratory, Lawrence Livermore National Laboratory, and Tyndall Air Force Base for homemade explosive characterization [1]. X-ray source, detector, and motional control hardware are specified as well as specimen platforms, containers, and reference material types. Most of the details on the LLNL and Tyndall systems are derived from References 2 and 3. The steps that constitute the raw data processing and CT reconstruction are also recorded. Sources for further information on the processing, and technical subsystems, are given in the Section 3 References.

Acronyms

CT	Computed Tomography
EDS	Explosives Detection system
HME	Homemade Explosive
kV	Kilovolt
LLNL	Lawrence Livermore National Laboratory
LAC	Linear Attenuation Coefficient
TAFB	Tyndall Air Force Base
TSL	Transportation Security Laboratory

Introduction

Objectives:

This document is intended to provide information on three high spatial-resolution computed tomography (micro-CT) scanners—one at the Transportation Security Laboratory (TSL), one at Lawrence Livermore National Laboratory (LLNL) and one at Tyndall Air Force Base (TAFB). Two of the scanners, LLNL and TAFB, are closely matched in components and geometry with the intent that results can be directly compared between the two systems. The TSL utilizes different x-ray sources, filtrations, and geometries that may produce results that differ from the other two systems. The differences will likely be due to the TSL's input x-ray spectra not being identical to that at LLNL/TAFB. In particular, the greater takeoff angle and reduced filtration will produce softer spectra in some of the Experiments. In the material that follows, any features that are not substantially identical will be called out separately. Additional details are given in the references listed in Section 3 References. Within constraints of practicability, some referenced documents are included in the appendices at the end.

The documentation is intended as a reference to inform users of the microCT results with those details that are needed to understand and evaluate the content and limits of that information.

The documentation will address the hardware and software components, their physical and functional relationships, the assembly of those components as an imaging system, and the salient parameters of their usage.

Overview

These micro-CT scanner systems are designed to measure and compare the physical properties of samples in the context of CT imaging. Each scanner includes a high-voltage, DC x-ray source, an area detector, a positioning system that provides “rotate-only” imaging, a sample-support stage and a double-slit collimator.

Samples are supported in two different planes. The upper plane includes a single sample which is the material to be characterized. The lower plane incorporates a number of known “reference” samples that are used for calibration and a reference for monitoring the stability and consistency of the imaging system. The two-slit collimator projects two multiple slice x-ray fan beams, one through each plane, while minimizing the x-ray scatter from objects not essential to imaging the portion of the samples transected by those fans. These fan-beam data are reconstructed as 2-D images.

Images are also made with the upper slit-collimator removed. These images are used either as 2-D radiographs, or reconstructed as 3-D (cone-beam) images. Prior to November 9, 2009, LLNL removed both slit-collimators to make these images.

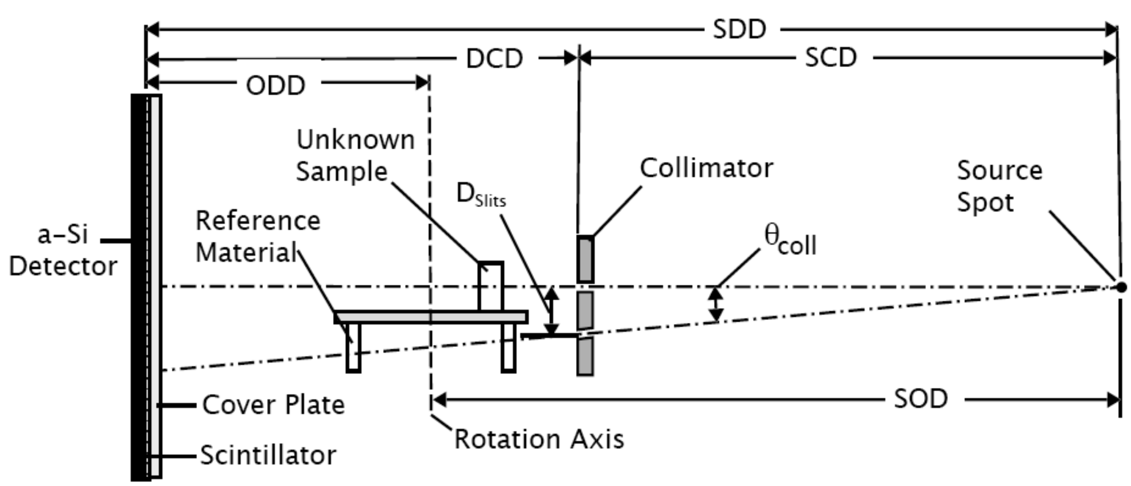

Figure 1. Micro-CT System Geometry*: Measurements are from the center of the source-spot, the detector side of the collimator, the rotational center of the table and the active surface of the scintillator.*

Micro-CT System Specifications

Hardware

Geometry

Critical Dimensions LLNL:

	Before 10.19.10	After 10.19.10
SDD[1]	1402.5 mm	1398.5
ODD	295.9 mm	293.1
SOD	1106.6 mm	1105.4
SCD	956.8 mm	953.3
Θcoll	1.50 deg.	1.50 deg.
Object Magnification	1.267	1.265

Critical Dimensions Tyndall:

SDD	1393.5 mm
ODD	278.5 mm
SOD	1115 mm
SCD	926.0 mm
Θcoll	1.55 deg.
Object Magnification	1.250

Critical Dimensions TSL (Exp. 1, 2, and 3 (Collimated and Open): before 7.01.10

SDD	1295.4 mm
ODD	317.5 mm
SOD	977.9 mm
SCD	772.0 mm
Θcoll	1.86 deg.
Object Magnification	1.325

Critical Dimensions TSL (Exp. 4, and Experiments 1 and 2 after 7.1.10

SDD	2286 mm
ODD	561 mm
SOD	1725 mm
SCD	1364.4 mm
Θcoll	1.05 deg.
Object Magnification	1.325

Sample Positioning

OSD	34.9 mm	Center of Rotation to Center of Specimen
ORD	63.5 mm	Center of Rotation to Center of References

Image-Pixel Dimensions:

Inherent Detector Pixel Size:	0.127 mm	
Re-Binned Pixel LLNL/TAFB (at Detector)	0.1905 mm	
Re-Binned Pixel TSL (at Detector)	0.2117 mm	
LLNL Image Pixel (at center of rotation)	0.150 mm	(before 10.19.10)
LLNL Image Pixel (at center of rotation)	0.151 mm	(after 10.19.10)
Tyndall Image Pixel (at center of rotation)	0.1521 mm	
TSL Image Pixel (at center of rotationr)	0.1597 mm	

Experimental Setup Sketches:

System Cabinet (Tyndall Only)	[D1]
Table Sketch (LLNL)	[D2]
Table Sketch (TSL)	[D3]

Functional Component Documents and Critical Specifications

X-ray Source (LLNL/TAFB):

Make:	YXLON	
Model:	Y.TU 450-D09	
Serial No LLNL:	61-0971	
Serial No. Tyndall:	59-1015	
Focal Spot (in use):	0.4 mm	
Target Material:	Tungsten	
Takeoff Angle:	11 degrees	Appendix 1: Target geometry
Anode-Cathode Axis: LLNL	Vertical: Anode on top	
Anode-Cathode Axis: Tyndall	Horizontal: Anode to the left facing detector	
X-ray Window:	5-mm Be	
HV Potential Range:	20–450 kV	
Current (Max):	7.0 mA (0.4-mm spot)	
Power (Max):	0.7 kW (0.4-mm spot)	
User Manual and Specifications:		[M1]

X-ray Source (TSL Exp. 1, 1 Open, 2, 3, 3 OPEN before 7.1.10):

Make:	Phoenix X-ray	
Model:	XS UNIT 160D	
Serial No.:	XS160D000F-140408	
Focal Spot (in use):	8 microns (approximate)	
Target Material:	Tungsten	
Takeoff Angle:	20 degrees	Appendix 1: Target geometry
Anode-Cathode Axis:	Horizontal: Anode to right facing detector	
X-ray Window:	0.5 mm Be	
HV Potential Range:	10–160 kV	
Current (Max):	3 mA	
Power (Max):	320 W	
User Manual and Specifications:		[M2]

X-ray Source (TSL Exp. 4 before 7.1.10. Exp 1 and 2 are included after 7.1.10):

Make:	YXLON	
Model:	Y.TU320-DO1	
Serial No.:	58-0867	
Focal Spot (in use):	1.9 mm	
Target Material:	Tungsten	
Takeoff Angle:	20 degrees	Appendix 1: Target geometry
Anode-Cathode Axis:	Horizontal: Anode to the left facing detector	
X-ray Window:	3 mm Be	
HV Potential Range:	15–320 kV	
Current (Max):	9.35 mA	
Power (Max):	640 W (1.9 mm spot)	
User Manual and Specifications:		[M3]

X-ray Source Controller and Power Supply (LLNL/TAFB):

Make:	YXLON	
Controller Model / SN: LLNL	MGC41 / A0031 1000013	
Controller Model / SN:	MGC41 ./ 1945203	
Power Supply Models:	MGG46/MGG47	
PS Serial Nos LLNL:	A303 212 0028/A303 408 0020	
PS Serial Nos Tyndall:	A303 175 0310/ A303 186 6501	
Potential (max/min):	450/20 kV	
Accuracy:	± 1 % of demand value ± 0.2 kV	
Current (max/min):	15/0.5 mA	
Accuracy:	± 0.2 % of demand value ± 0.01 mA	
Max Power:	1.5 kW	
Manufacturers Specifications:		[M4]

X-ray Source Controller and Power Supply (for Phoenix source):

Make:	PHOENIX X-RAY	
Controller Model / SN:	PHOENIX/BEDXR00001-140408	
Power Supply Model:	Block (Transformer)	
PS Serial No:	Not Available	
Potential (max/min):	160/10 kV	
Accuracy:	Not Available	
Current (max/min):	3/0.005 mA	
Accuracy:	Not Available	
Max Power:	320 W	
Manufacturer’s Specifications:		[M2]

X-ray Source Controller and Power Supply (for Yxlon source):

Make:	YXLON
Controller Model / SN:	MGG42/Not Available
Power Supply Model:	MGP41

PS Serial No:	1156609	
Potential (max/min):	320/15 kV	
Accuracy:	± 1 % of demand value ± 0.2 kV	
Current (max/min):	9.35/0.5 mA	
Accuracy:	± 0.2 % of demand value ± 0.05 mA	
Max Power:	640 W (1.9 mm spot)	
Manufacturer's Specifications:		[M4]

Collimator: [D4]

Material:	l5.9 mm thick tungsten
Slit Separation (D_{slits})	25.0 mm (center to center, source side)
Slit Width	2.0 mm (set by shim)
Slit Length	330.2 mm

Sample-Positioning Tables:

Make:	Newport
Controller LLNL:	Model ESP7000 SN: 1250
Controller Tyndall:	Model XPS-C6 SN: 1385WEEE13AUG05
Controller TSL:	Model XPS-C8 SN: 05132100
Translation Stage LLNL :	IMS400CC, SN B03-2060
Translation Stage Tyndall :	Model IMS600LM
Translation Stage TSL:	Model IMS500CC, SN B05-0117
Rotary Stage LLNL:	RVS120PP, B02-5532
Rotary Stage Tyndall:	RVS80PP
Rotary Stage TSL:	RVS120PP, SN B05-2112

Table 1. *Kodak Lanex Fine scintillator specifications* [4]

Item	Material	Density (g/cm^3)	Thickness (mm)	Areal Density (g/cm^2)	% of total integrated areal density
Protective Coating	Cellulose acetate	1.32	0.010	0.00132	9.30
Plastic Substrate	PTFE	1.38	0.178	0.02460	10.20
Scintillator	Gd_2O_2S + urethane binder	4.25	0.084	0.03570	11.60
Protective Coating	Cellulose acetate	1.32	0.005	0.00066	11.60

Detector:

Make:	Thales
Model:	FlashScan 33 fine
Serial No LLNL:	93242914 (before 7/21/11)
Serial No LLNL:	91106194 (after 7/21/11)
Serial No Tyndall:	91169523
Serial No TSL:	91198438
Front Panel:	1.5-mm Carbon Composite, 0.206 g/cm^2
Scintillator (LLNL, TAFB, TSL)	Kodak Lanex Fine (Gadolynium Oxy-Sulfide)

Scintillator (TSL)	Kodak Lanex Regular (Gadolynium Oxy-Sulfide)
kV-monitoring Cu strip nom. thick. at 8.96 g/cm^2	LLNL 1.13 g/cm^2 (1.26 mm nominal thickness) TAFB 0.071 g/cm^2 (0.634 mm nominal thickness)
Manufacturers Spec.:	[M5]
Operating Manual:	[M6]
Time Selection Settings:	Table 3 and ThalesDial-Settings.txt
Outline Sketch	[D6]

Scan-Control Computer:

Make:	Dell
Model/SN LLNL:	DHM/ J4271
Model/SN Tyndall:	Optiplex 755/ Service Tag: HN09NK1
Model TSL:	Precision 380
Operating System:	Windows XP Pro

Samples:

Reference Materials: Nominal Composition and Density

99% Graphite	1.61
95% Denatured Ethanol	0.81
Delrin	1.412
Distilled Water	1.000
Teflon	2.160
6061 Aluminum	2.693

Solid Reference Material Diameters (nominal): 12.7 mm

Liquid Container for Ethanol and Water

Material:	Polypropylene
OD, ID at imaging plane:	14.0 mm, 10.8 mm

Former Test-Sample Container (LLNL):

Material:	Polypropylene
OD, ID at imaging plane:	29.3, 27.15 .mm

Test-Sample Container (TSL/TAFB, Current LLNL):

Material:	Low-density polyethylene	Nalgene: 2103-0002
Nominal OD, Wall thick:	38.9 ± 1.5 mm, 1.0 mm	

Sample/Material Positions: [D4]

Sample Carousel Design [D5]

Scan-Parameters:

Angular range:	0. – 199.5 degrees
Angular steps:	0.5 degrees
Direction of rotation:	Clockwise

Frame averages per image: 4

Spectra:

Table 2. *Filter thicknesses for various source spectra. The copper filter is 99.99% pure, the aluminum is a 6061-T6 aluminum allow.*

Exp. #	Source kV	LLNL Filtration		TAFB Filtration		TSL Filtration (before 7/1/10)		TSL Filtration (after 7/1/10)	
		Al-alloy (mm)	Cu (mm)	Al-alloy (mm)	Cu (mm)	Al-alloy (mm)	Cu (mm)	Al-alloy (mm)	Cu (mm)
1	160	1.943	1.905	1.943	1.905	NONE	1.905	NONE	1.905
2	100	1.943	NONE	1.943	NONE	1.69	NONE	2.58	NONE
3	160	1.943	NONE	1.943	NONE	2.000	NONE	Not Applicable	Not Applicable
4	300	1.943*	2.972	1.943	2.972	NONE	2.154	Not Applicable	Not Applicable

*1.943 Al Filter added to LLNL Experiment 4 beginning 1 October 2010.

Table 3. *Source current and detector integration time settings. For most of HME Set 1, the TAFB integration time was somewhat uncertain due to hardware issues.*

Exp. #	Source kV	LLNL		TAFB		TSL (before 7/1/10)		TSL (after 7/1/10)	
		Current (mA)	Int. Time (s)	Current (mA)	Int. Time (s)	Current (mA)	Int. Time (s)	Current (mA)	Int. Time (s)
1	160	4.35	2.80	4.3	2.26	0.9	2.08	2.60	2.08
1 OPEN	160	4.35	2.80	4.3	2.26	0.9	2.08	2.60	2.08
2	100	1.1	3.16 3.52**	1.55	2.26	0.3	2.08	1.15	2.08
3	160	0.7	2.26	0.65	2.26	0.125	2.08	Not Applicable	Not Applicable
3 OPEN	160	0.7	2.26	0.6	2.26	0.125	2.08	Not Applicable	Not Applicable
4	300	2.3	2.09	2.3	2.26	0.75	2.08	Not Applicable	Not Applicable

** Exp. 2 integration increased as of July 27, 2011.

TSL/LLNL/TAFB MicroCT Systems Similarities and Differences

The intent was to have all three CT systems at TAFB, LLNL, and TSL to be the same. However, given that they were not all designed and built at the same time, and for the purpose of scanning HMEs, they have some distinct differences—some intentional, some inadvertent. The differences and the plans to retain or resolve those differences are discussed below.

1) Due to facility considerations, the Tyndall x-ray system was assembled inside a shielded cabinet, whereas the LLNL and TSL systems were assembled in a radiation-shielded room. While there may be a little more x-ray scatter inside the shielded cabinet, there are no indications of significant differences due to scatter in the data.
2) The LLNL system was assembled with the anode-cathode axis oriented vertically; the axes of the Tyndall and TSL systems are horizontal (i.e., the LLNL x-ray source is rotated 90 degrees with respect to the TSL/TAFB sources).
3) In the initial system integration, placements of the motion table and detector relative to the source are different in the three systems. The differences between the LLNL and Tyndall systems are insignificant with regard to the properties of the images. The TSL geometry used before 7/1/10 is also similar to the TAFB/LLNL geometry for all data collected below 300 kV. The 300 kV TSL data, and the lower-energy data collected after 7.01.10, is acquired using a geometry that is significantly different from the TAFB/LLNL systems.
4) For measuring the detailed attenuation properties of the samples the x-rays are collimated through a two-slit aperture scatter-reduction collimator. For measuring texture, the sample is viewed without scatter collimation by removing the top collimator section. For the HME Set 1, LLNL removed the full collimator for the initial formulations.
5) As shown in Table 2, the spectral filtrations for the TAFB and LANL systems are essentially identical. The TSL filtrations are somewhat different.
6) To maintain proper signal levels for different spectra it is necessary to adjust the integration time of the detector and/or the mA of the x-ray source. The particular choices of settings are unique to each instrument (Table 3). Due to hardware problems, the actual integration times for TAFB may not be accurate.
7) For the first part of the program (HME set 1) different containers were used for the LLNL test samples than for TAFB and TSL.
8) In order to monitor changes in x-ray source kV, a strip of copper is affixed to the left side of the detector cover. The location used by TAFB is farther off axis than that used by LLNL. The TSL copper strip is located on the right side of the detector for ease of access to remove the strip for correction images.
9) The locations of the TAFB/TSL and LLNL reference materials and specimens on the carousel were laid out differently for the HME Set 1 measurements.
10) The TSL system required that a different x-ray source be used for the 300 kV data collection than was used for the 160 and 100 kV scans. LLNL and TAFB used the same x-ray source for all data collection. . After July 1, 2010 the TSL discontinued using the Phoenix XS160D source and relied solely on the Yxlon Y.TU320-DO1 source.

Procedures

System Alignment

Alignment of the detector panel to the tube head and determination of the beam center are described in Reference S0.

X-ray Source Warm-up

X-ray source warm-up procedures follow the directions in the x-ray source user manuals for TAFB and LLNL (M1] and for TSL [M2, M3].

Detector Calibration

Detector calibration procedures follow the manufacturer's instructions provided in the detector user manual [M6].

Data Acquisition

The data acquisition procedures are laid out in Reference 1. The detailed steps used for LLNL micro-CT scans are documented in Reference S4].

Data Naming Examples: (formats used at the data-acquisition facilities).

Within the data folders, the formats are specified in ImgrecManual-V10.doc.

LLNL Data Folder: Specimen4/RX_62_AB100Al:
- RX_62_AB1 is the object,
- 100kV Al, 160 kV Al, 160 kV Al Cu, 300 kV Cu are the spectra

Tyndall Data Folder: Z3A3/Exp1:
- Z3A3 is the object
- Exp1, Exp2, Exp3, Exp4 correspond to the definitions in Table 2

Data Folder to TSA:
- HME Unclassified Code Name (for example Z5d-1)
- § Exp1
    - Projections
    - Reconstructed LAC
  - HME
  - Standards
- § Exp1_Open
    - Projections
    - Reconstructed LAC
  - HME
  - Standards

etc., through Exp4.

Data Processing and Reconstruction

The steps used in processing the radiographic data and in obtaining the reconstructed images are described in Reference S1. The detailed operation of the software, used in reconstructing the data is provided in the ImgRec User Guide [S2]. These processing steps are guided by the imaging parameters in the "SCT" file. Definitions of the data items used in this file are provided in Reference D7.

Data Analysis

The data-analysis process segments and extracts the key image data and statistically analyzes those relevant regions. This process is documented in Reference S3.

References

Copies of these references can be obtained upon request.

Published Documents

1. R. Krauss, and R. Klueg, *Standard Operating Procedure: Industrial Computed Tomography System Data Collection of Home-Made Explosives*, DHS/STD/TSL-XX-XX, B-09-11-S-v, August, 2009.
2. J. Smith, D. Schneberk, J. Kallman, H. Martz, D. Hoey, *Documentation of the LLNL and Tyndall Micro-Computed-Tomography Systems*, LLNL-TR-421377, Version 091216, Dec. 17, 2009.
3. R. Krauss, R. Klueg, J. Smith, D. Schneberk, J. Kallman, H. Martz, and D. Hoey, *MicroCT Specifications for HME Data Collection*, DHS/STD/TSL-xx/ss Draft, March 2010.
4. E. Schach von Wittenau, C. M. Logan, M. B. Aufderheide III, and D. M. Slone, *Blurring artifacts in megavoltage radiography with a flat-panel imaging system: Comparison of Monte Carlo simulations with measurements*, Med. Phys., 29 (11), November 2002.

Standard Operating Procedures

S0 K. Morales, *Alignment of Panel to Tube Head*

S1 D. Schneberk, *CT Reconstruction for HEAF acquired data of Home Made Explosives Materials*, Version 1.4, November 7, 2009.

S2 D. Schneberk, *Imgrec User Guide, CT Pre-processing, Reconstruction, and Image Processing and Image Inspection Tools*, Version 10.0, November 10, 2009

S3 J. Kallman, *Analysis Procedures for CT Reconstructed data of Home Made Explosives Materials acquired at Tyndall or HEAF*, Version 10.0, October 15, 2009.

S4: K. Morales, *Sample Checklist*

Manuals

M1 UM_YTU450D08,9 F02.pdf

M2 vtomex_s_160D_V2.0_en.pdf

M3 Y.TU 320-D01/D03.pdf

M4 YXLON_MG325_452_EN.pdf

M5 FlashScan33.pdf

M6 FS35usermanual.pdf

Drawings and Other Associated Documents

D1: TAFB 450 kV Cabinet.pdf

D2: LLNL Experimental Setup.pdf

D3: TSL Experimental Setup.pdf

D4: Collimator Drawings.pdf

D5: Carousel Drawings.pdf

D6: FS 33 outline.pdf

D7: SCT file Definitions.xls

D8: Detector Panel Holder Drawings (26 drawings).

Appendices

Appendix 1. X-ray Anode Geometry

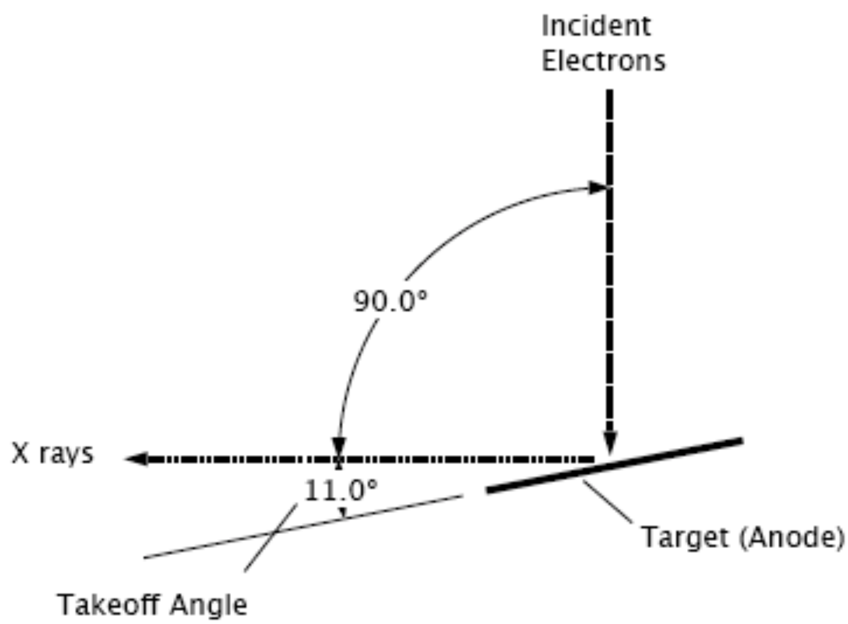

Figure A1_1. *The geometry of the x-ray target and the definition of "Takeoff Angle" are shown. The vector marking the exit path of the x rays, defines the "central ray" of the CT system. System alignment sets this ray normal to the surface of the detector and locates the position (row and column) of incidence. TSL takeoff angles are 20°.*

Appendix 2. MicroCT Carousel Layouts (Part No. 03-341-75A)

To get a quantitative determination of the layout of the various samples and reference materials on the LLNL and Tyndall micro-CT systems, Several 100-kV images were taken from each of the configurations, the image center was located, the angular positions required to center the images of one of the reference materials and of the unknown sample were noted, and the relative angular positions of the sundry reference materials were checked.

Object center-positions were determined using "lineouts" through the edges of each image. The resulting angular positions are shown in the three figures below to an accuracy of about ±0.5 degrees.

Three reference-sample configurations were used during the HME-1 experiments; these are shown in the attached figures.

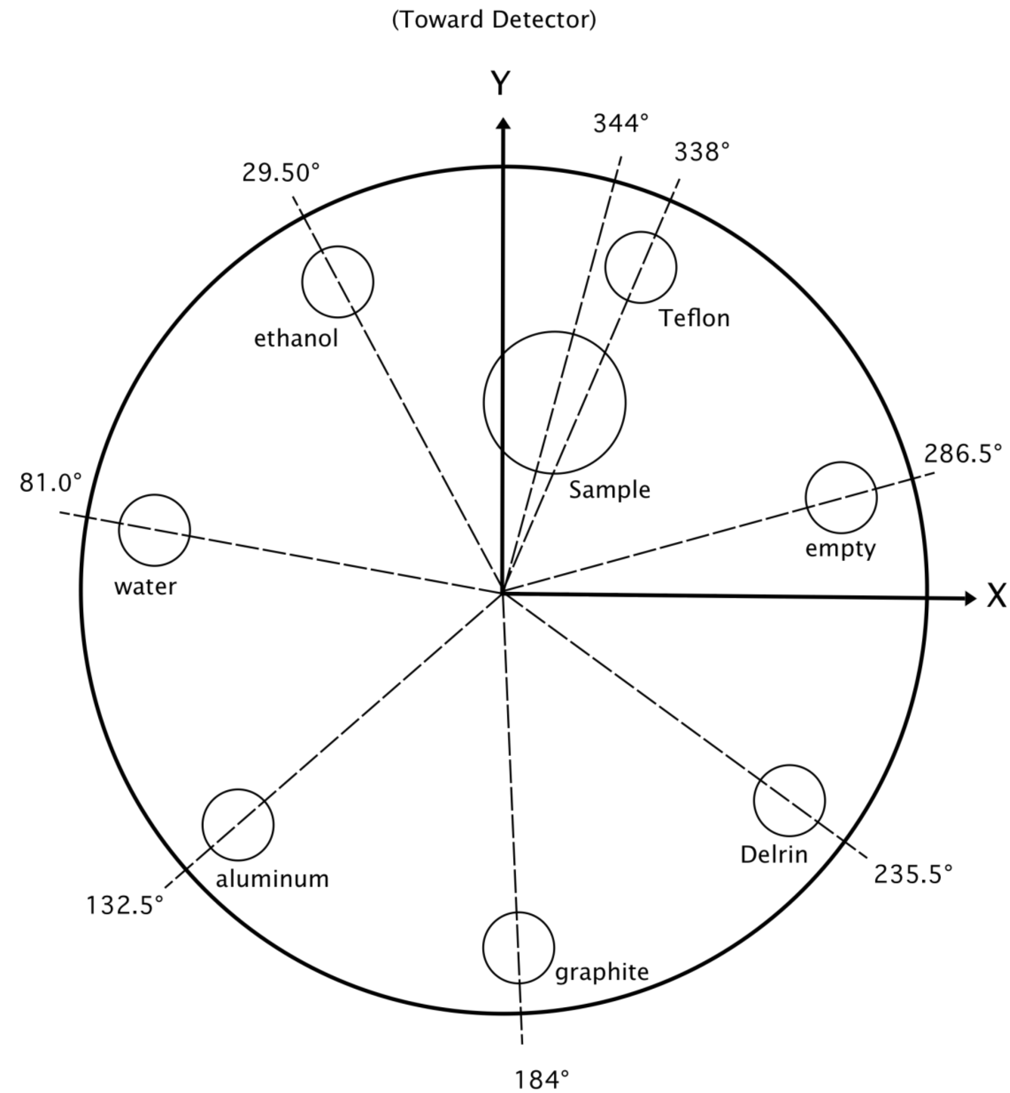

Figure A2_1. *LLNL Sample Carousel used before 11.09.09. The table is viewed from above in the initial position; rotation is clockwise.*

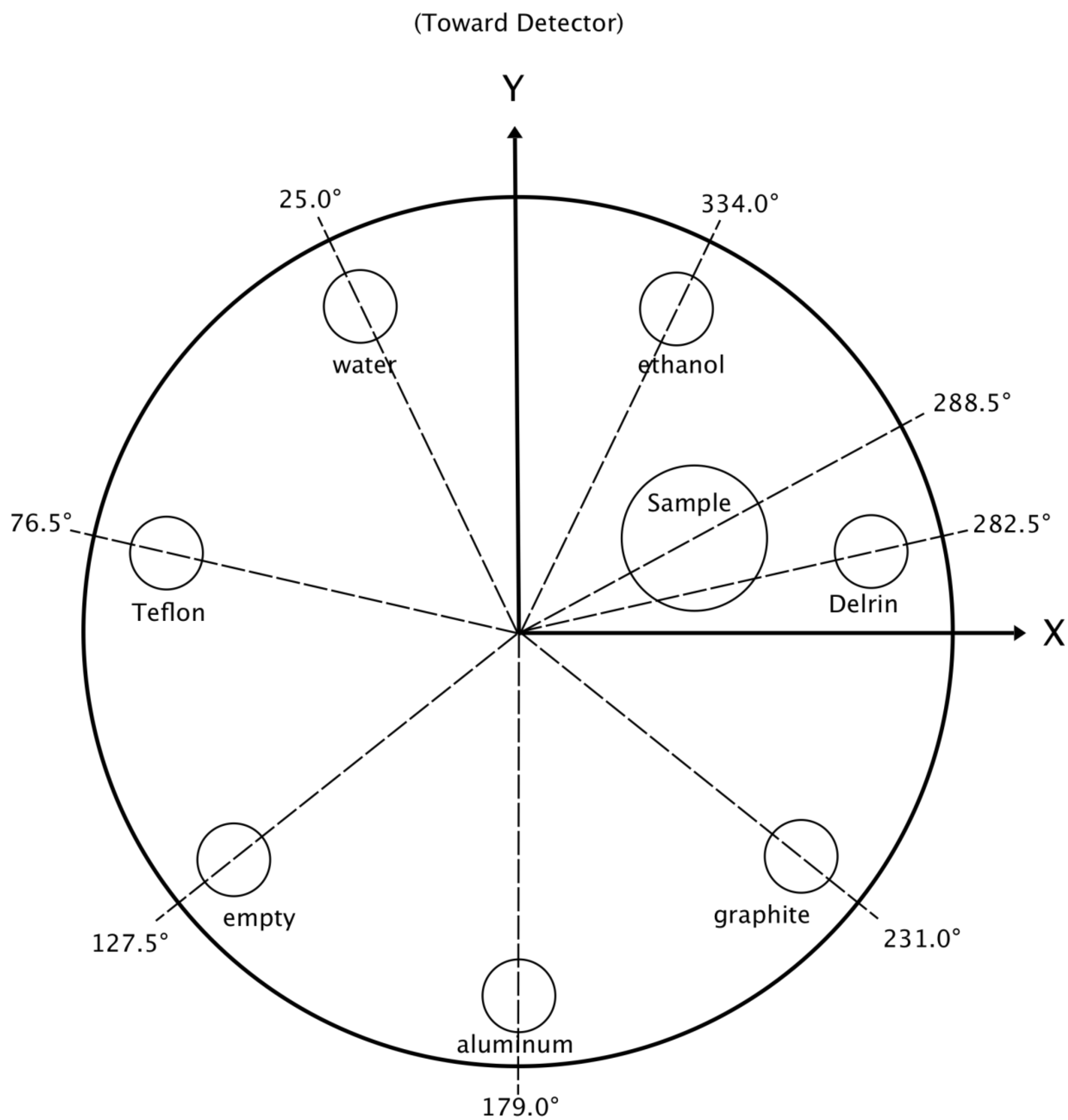

Figure A2_2. *LLNL Sample Carousel adopted 11.09.09. The table is viewed from above in the intital position and rotates clockwise.*

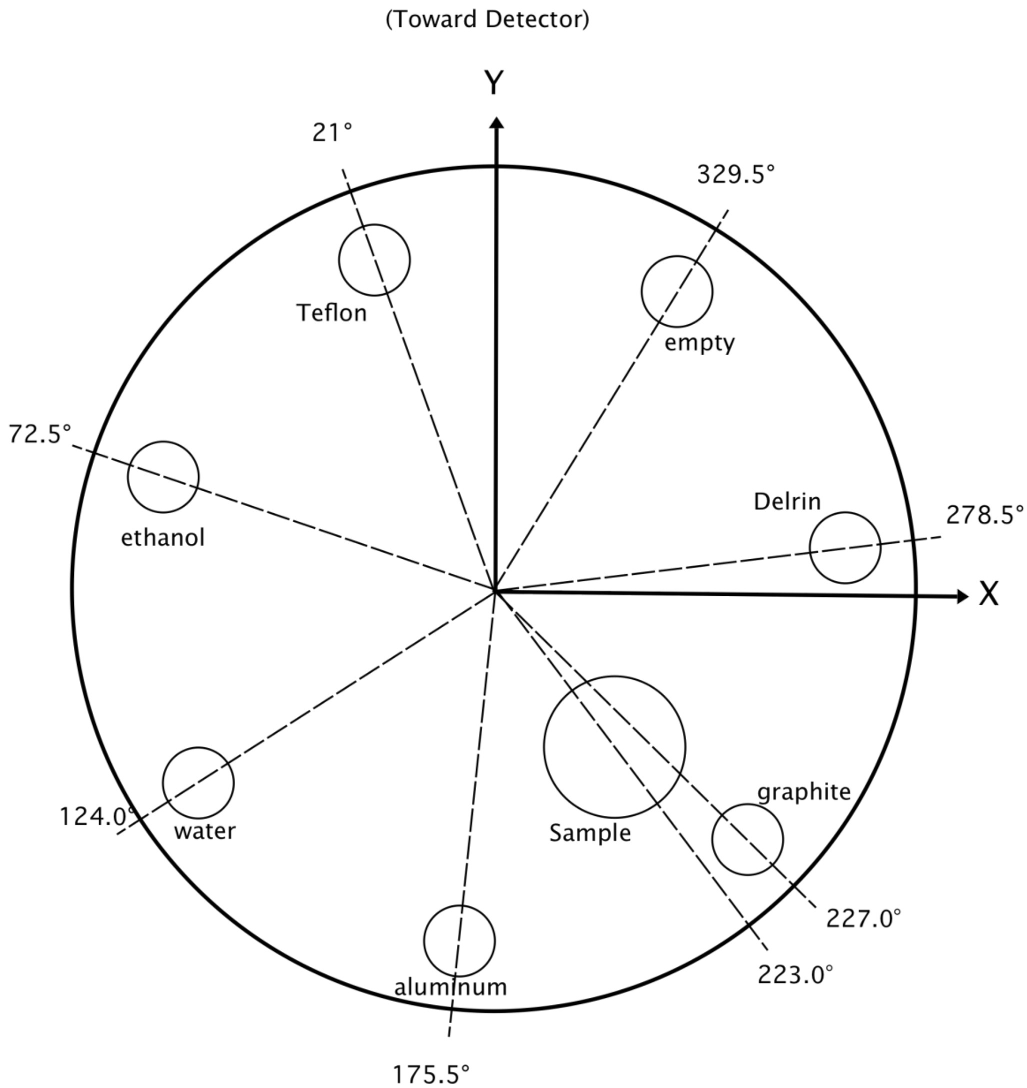

Figure A2_3. *TAFB and TSL Sample Carousel. The table is viewed from above in the initial position and rotates clockwise.*